

## THE ELASTIC LIMIT OF METALS.

COMMON SENSE, as Lebasteur has remarked, prevents us from denying the existence of a limit of elasticity in metals. It is true that the smallest load on a test-piece will cause a slight permanent set. Nevertheless, such structures as iron railway bridges retain their shape, and if a piece of metal is subjected to a small stress many times in succession, recovery after each application becomes almost perfect. What, then, is the elastic limit? The Commission des Méthodes d'Essai of 1894 announced that it is necessary to recognise three such limits:—

(1) The theoretical limit of elasticity or the maximum stress which does not produce a permanent strain (of more than a certain small amount).

(2) The proportional limit of elasticity, within which the strain is proportional to the stress.

(3) The apparent limit of elasticity, corresponding to the "breaking-down" point of ductile metals. Above this point, perceptible increases in deformation occur without a perceptible change of load.

With regard to these limits, M. Frémont points out, in a carefully reasoned article contributed to the September number of the *Bulletin de la Société d'Encouragement pour l'Industrie nationale*, that no one can say what is the exact difference between the first two, and that there are theoretical grounds for supposing that they ought to coincide. Moreover, the proportionality of deformation has been called in question, slight irregularities having been detected when the measurements were made with the greatest care.

These matters, however, do not greatly interest the practical man. It is not usual for the elastic limit of a consignment of steel to be tested, although it is frequently mentioned in specifications. As a general rule the breaking load only is measured, and it is assumed that the elastic limit is a definite constant fraction of this. In view, however, of the tendency of engineers to avail themselves more fully of the elastic limit, it is becoming more important to determine that limit exactly. In fact, if the elastic limit were known with a greater degree of exactness, it might be possible to practise economy by using a smaller margin of safety than is necessary at present.

Holding these views, M. Frémont set himself the task of discovering whether there is a real limit of elasticity, and if the anomalies mentioned above could be explained. Calling to mind the dictum of seventy or eighty years ago that a metal had passed its elastic limit if it had undergone a change of texture under stress, he proceeded to examine how far the microscopic structure of metals was altered by the first permanent strain.

In the class of bodies with well-marked breaking-down points, such as good mild steel, it can be readily observed in polished sections at a magnification of 50 diameters that all the grains, without exception, are clearly deformed, at what seems to be the real elastic limit. These bodies are nearly homogeneous, and if part of a test-piece is permanently deformed, the line of demarcation is clearly defined on a polished surface by the deformed part becoming dull, the change being visible even without magnification. In general, however, the first deformations are local, owing to the unequal distribution of stresses. It is almost impossible to adjust the test-piece so that the force may act in a straight line in the direction of its axis, and so the test-piece is generally deformed obliquely. Local action is strikingly illustrated by the fracture of some cast-iron or other hard non-ductile test-pieces at a place in the head where the section is greater than elsewhere.

Various devices have been invented to overcome this defect, but in none of them is any account taken of the effect of stress-hardening. The effect is well known, and may be readily demonstrated by a simple experiment. Mark a prismatic test-piece with a punch, and then file off the mark and polish the metal. If the prism is then compressed between two end-pieces the mark will reappear as soon as the elastic limit has been sufficiently passed. The stress-hardened parts resist more than, and do not lose their polish so easily as, the unaltered portions of the test-piece. The principle is the same as in the magic mirrors of the East, and the effects are observable in actual tests. Traces of striæ, file-marks, the marks made by the jaws of the vice in which the test-piece was held while it was being prepared, all reappear in the course of testing. Similarly, if the force in testing is not applied equally, the part which bears the greatest stress will be deformed first, and *ipso facto* hardened and strengthened. The first giving-way of the metal causes the pressure to be more evenly distributed, but the irregularity of pressure is succeeded by irregularity of resistance, which continues to the end of the test.

In some experiments on homogeneous boiler-steel M. Frémont found that a permanent set could be obtained in compression tests under loads varying from 8.55 to 15.70 kilograms per square millimetre, but judging from the dulling of the polished section, the deformation was always local, and the elastic limit was not passed, except in isolated patches of the metal.

After painstaking but vain efforts to adjust the force accurately, he fell back on the use of test-pieces of gradually increasing section. Then the first irregular deformations occurred in the weakest section; there was a local sinking and adjustment, and the discontinuous dulled lines tended to lie flat at right angles to the force. As the force increased the lines approached each other, and coalesced to form a continuous sheet the area of which could be measured and compared with the stress.

In Fig. 1 the effects of compression are shown on the four polished faces of a test-piece having the shape of a truncated pyramid. The first effects are quite discontinuous, the dark lines near the upper part of the top row of photographs showing the areas which have received a permanent set. In the second row the effect of a maximum pressure of 1015 kilograms is shown. In the third row, under a pressure of 1155 kilograms the discontinuous lines have coalesced, and the deformation has been made to advance as a continuous sheet, the area of which amounted to 46.8 square millimetres, so that the real elastic limit was found to be 24.60 kilograms per square millimetre. The last two rows of photographs show the effects of pressures of 1295 kilograms and 1435 kilograms respectively, corresponding to elastic limits of 24.80 and 24.65 kilograms per square millimetre. The same metal was used as that which underwent local deformation in an ordinary trial under a pressure of 8.55 kilograms per square millimetre of the whole section.

Similar results were obtained by M. Frémont in tension tests. The first deformations were apparent under a force of 8.5 kilograms, although the real limit of elasticity was certainly above 21.5 kilograms. Tests on thin flat test-pieces of increasing section gave results shown in Fig. 2, where the strained parts, at first discontinuous, subsequently form a continuous sheet.

The conditions are different in determining the elastic limit of the class of bodies which show no definite breaking-down point. The members of this class, which includes hard steels and metals of small elongation, are less homogeneous, and consist of networks of substances of different elastic limits. In the

first permanent deformations some grains only are deformed slightly, and as the stress augments more grains are deformed, and the deformation of the others increases. No definite dulling of the polished metal visible to the naked eye takes place, and the effects must be studied by means of the microscope. The polishing must also be done with the greatest care. The line of demarcation between the permanently strained and unstrained parts is even then always confused, and its exact position a little doubtful, but otherwise there is no difference between the testing of the two classes. In all cases the surface to be examined must be polished, for a scale of oxide has an elastic limit different from that of the metal underneath, and its indications are untrustworthy.

Similar results are obtainable in tests of flexion, torsion, &c.

By his experiments M. Frémont has proved that the

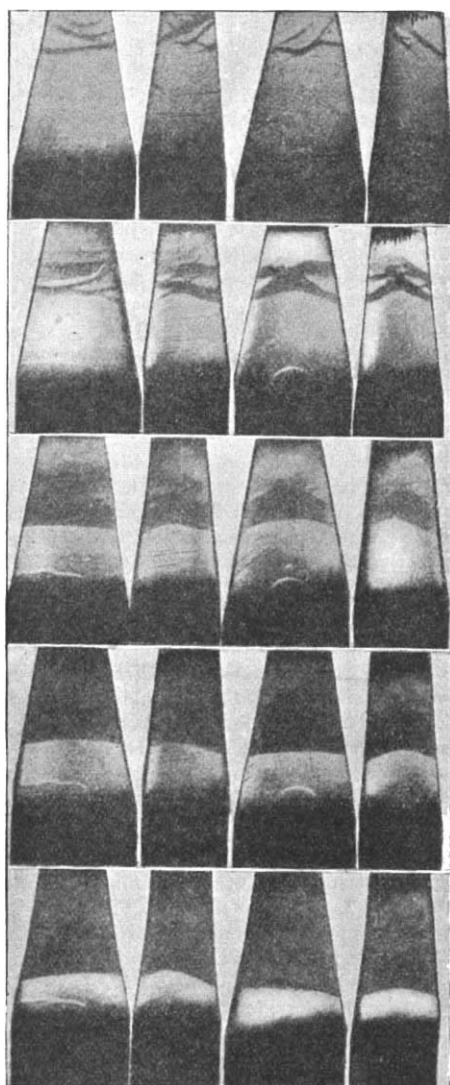


FIG. 1.—The dark areas at the upper parts of the test pieces show where the metal has given way under compression.

*theoretical elastic limit* is the mean charge per unit of section on which the real elastic limit is locally attained at a point of the piece tried. It is not the elastic limit of the metal, but of the particular piece

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of metal under the special conditions employed. Its value depends on care in adjustment, &c.

The *proportional elastic limit* is still more fortuitous. Owing to compensating errors the line showing the relation between stress and strain may continue to be fairly straight even above the theoretical limit.

The *apparent limit* is the mean charge per unit of section when the real elastic limit is reached in all regions where it had not previously been reached. It is nearer the real limit but is not identical with it, because the charge is unequally distributed between the parts that have been previously hardened and those that are not yet hardened.

When the appearance of the lines of Lüders, which are now seen to be portions of metal which have given way, does not precede the continuous sheet, the theoretical limit and the apparent limit will coincide with the real limit. Generally, however, the lines come first and then the various limits will not coincide.

The nature of the metal has also an effect, for in annealed steel the two limits are nearer than in hardened and tempered steel.

To sum up, M. Frémont claims with much force that there is only one elastic limit of a metal, the "real elastic limit," as determined by the method he indicates. The real limit alone has the characters of a physical constant. The other so-called limits depend on the appearance of discontinuous deformations, the presence of which is almost inevitable in practice, although their cause is purely accidental.

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FIG. 2.—The dark areas on the test pieces correspond to the portions of the metal which have given under tensile stresses.

#### PREHISTORIC STUDIES IN AUSTRIA.

THE concluding part of the first volume of reports of the Prehistoric Committee of the Vienna Academy of Sciences has recently been published.<sup>1</sup> In former parts accounts have been given by Dr. Szombathy of excavations in the well-known cemetery at Hallstatt, of tumuli at Gemeinlebarn and Langenlebarn, and of the cemetery at Idria. Dr. Franz Heger has also treated of work carried on at Hallstatt in 1877 and 1878, as well as of various researches in Hungary and Lower Austria, while Dr. Moriz Hoernes and others have communicated valuable reports.

The part now issued contains two reports. The first, by Julius Teutsch, relates to some late Neolithic settlements with painted pottery in the valley of the Alt or Aluta, in the neighbourhood of Kronstadt, in Transylvania. A remarkable feature in one of the de-

<sup>1</sup> "Mittheilungen der Prähistorischen Commission der Kais. Akademie der Wissenschaften." 1 Band. (Vienna: Carl Gerold's Sohn, 1903.)